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(54) **SURGE PRESSURE REDUCTION APPARATUS WITH VOLUME COMPENSATION SUB AND METHOD FOR USE**

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(52) **U.S. Cl.** **166/386**; 166/383; 166/285; 166/332.4; 166/334.4; 166/319

(58) **Field of Search** 166/383, 386, 166/332.4, 332.5, 334.4, 285, 318, 319, 323, 374; 138/30, 31

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(57) **ABSTRACT**

A device for providing surge pressure reduction with volume compensation and methods of use are presented. Surge pressure reduction and volume compensation are accomplished by pressure-actuated release of the compensation device.

35 Claims, 10 Drawing Sheets

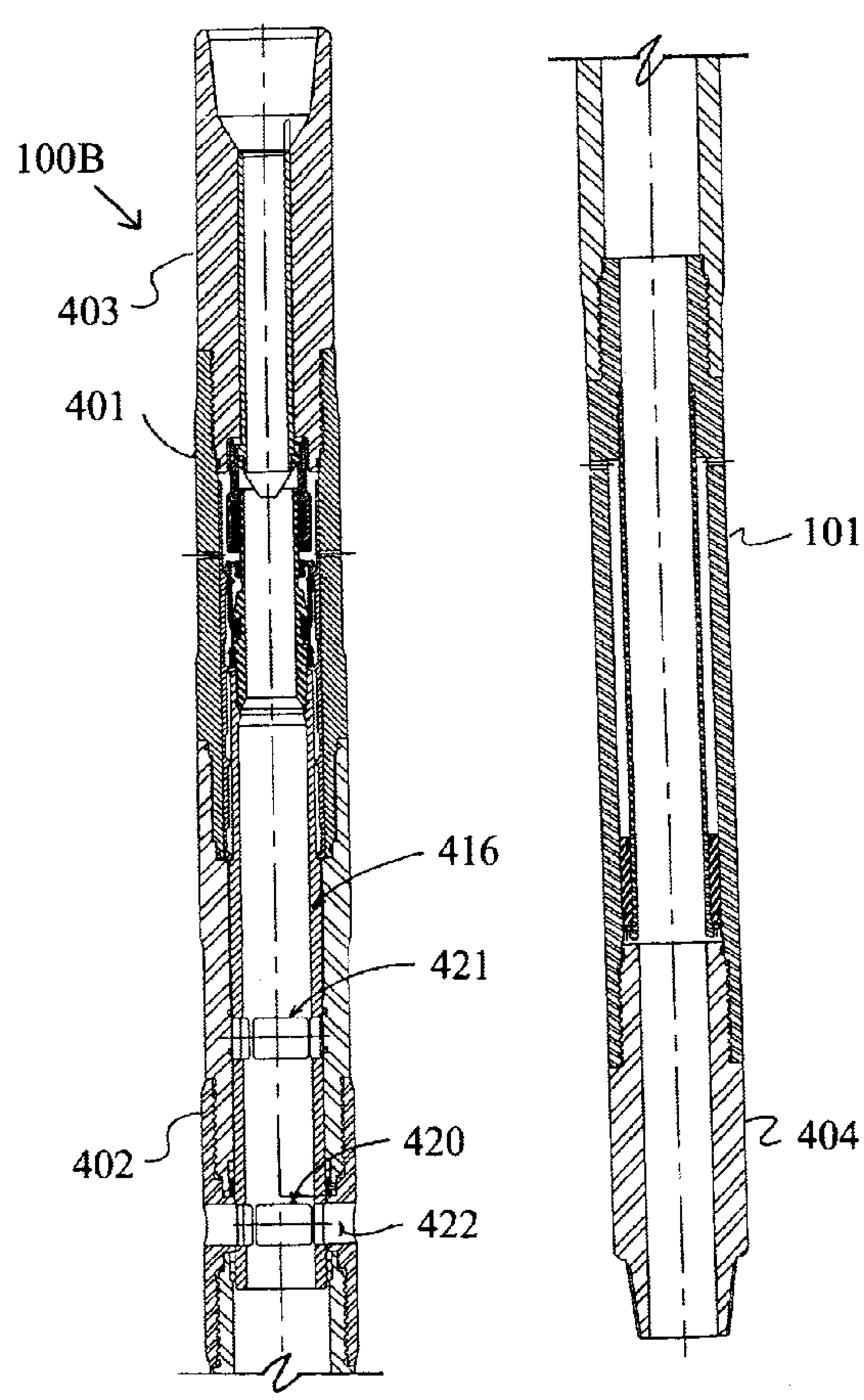


Fig. 1

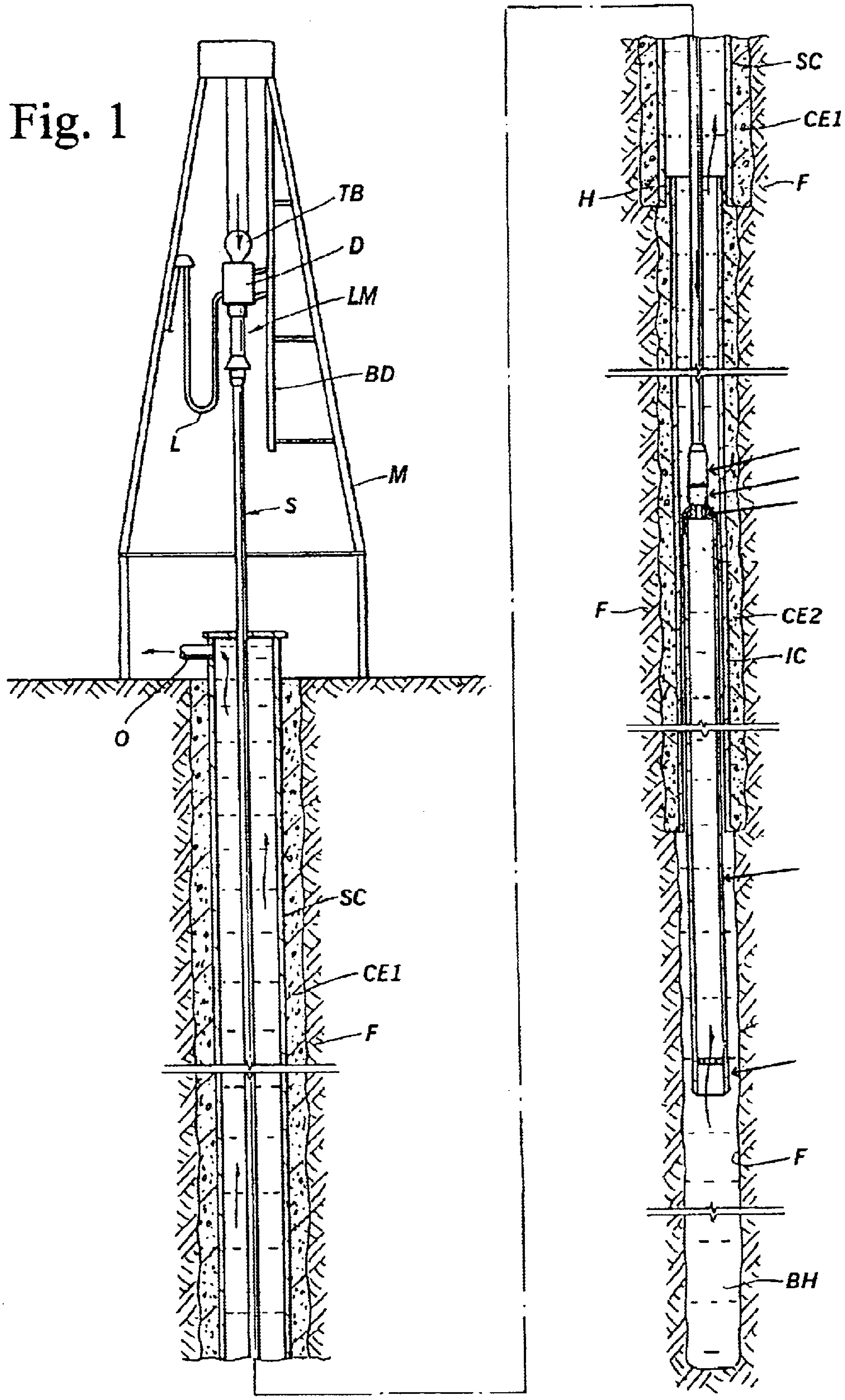
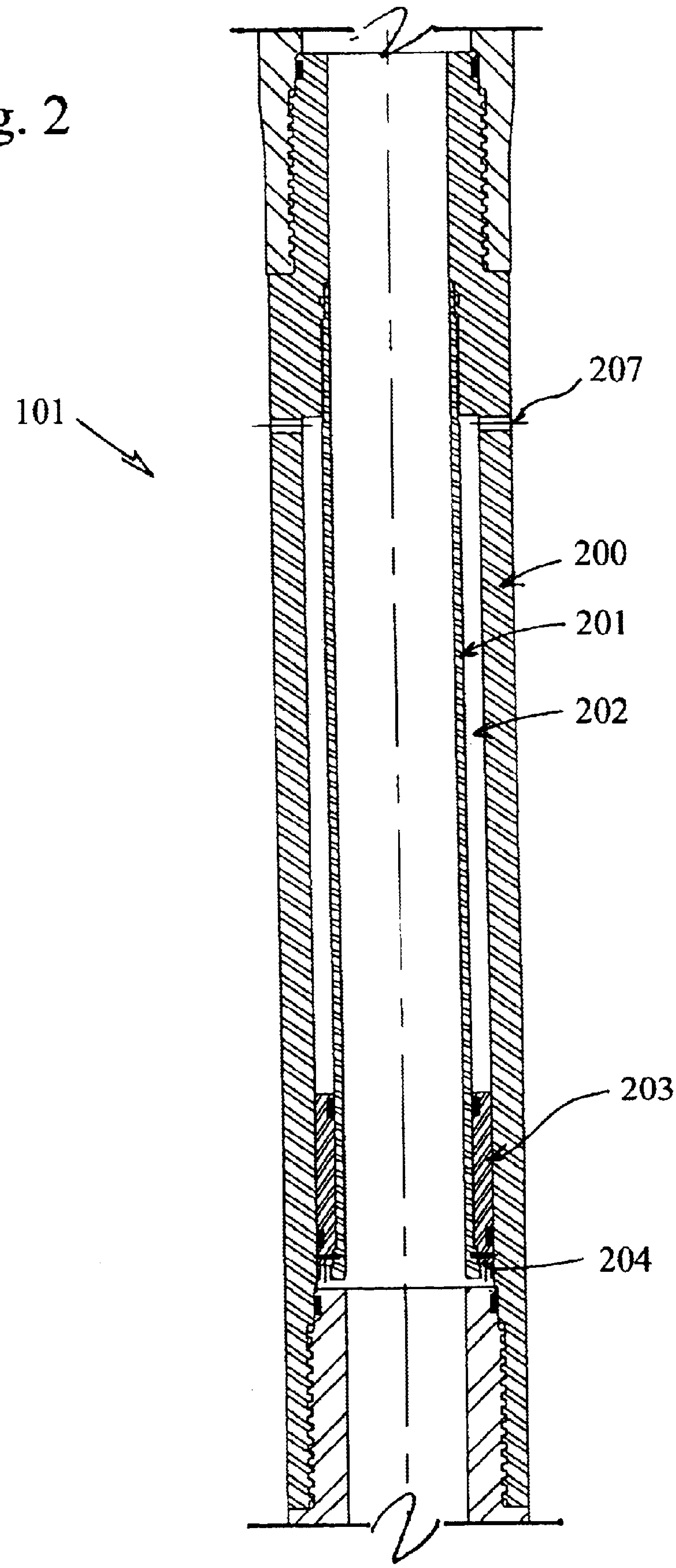


Fig. 2



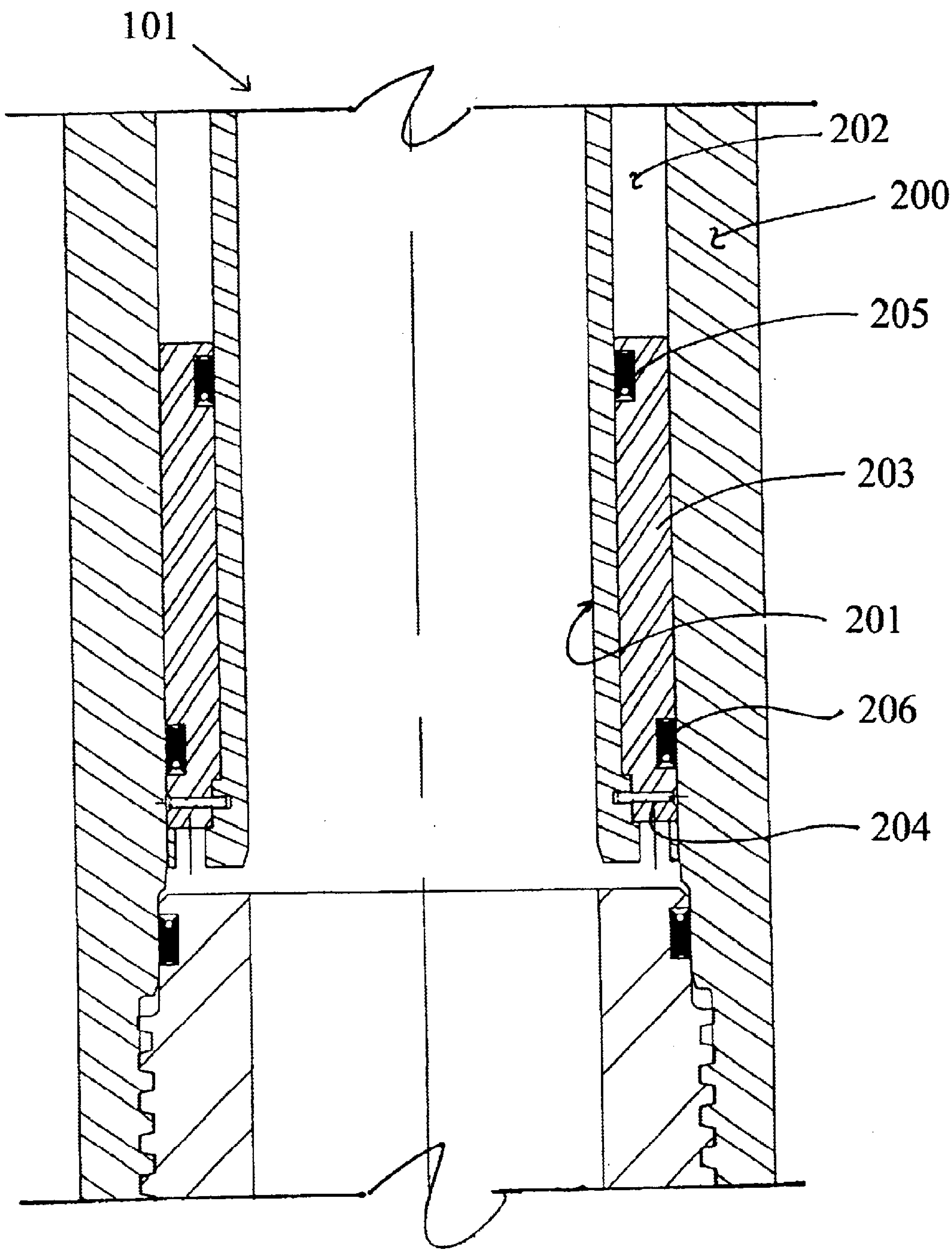


Fig. 3

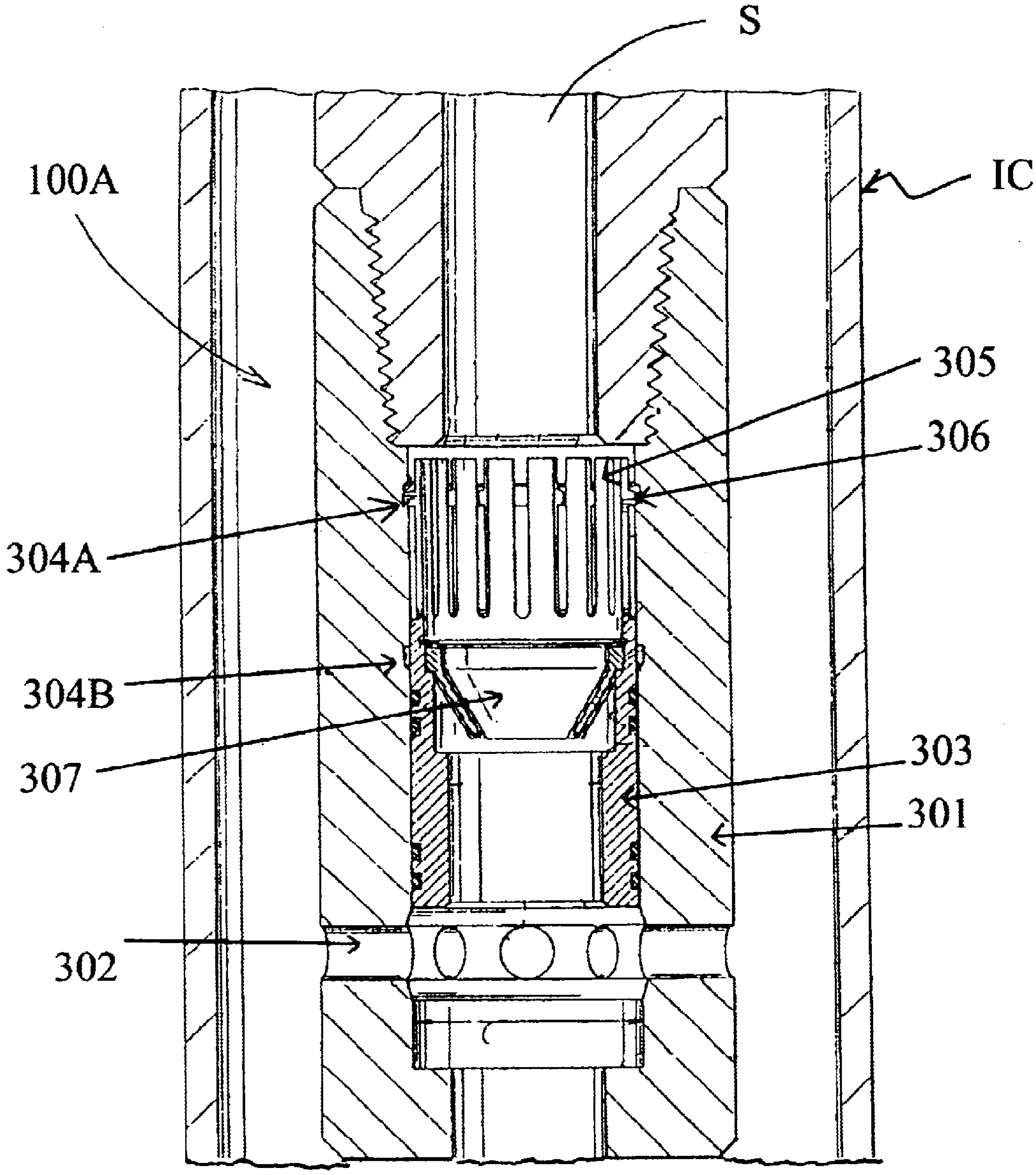


Fig. 4

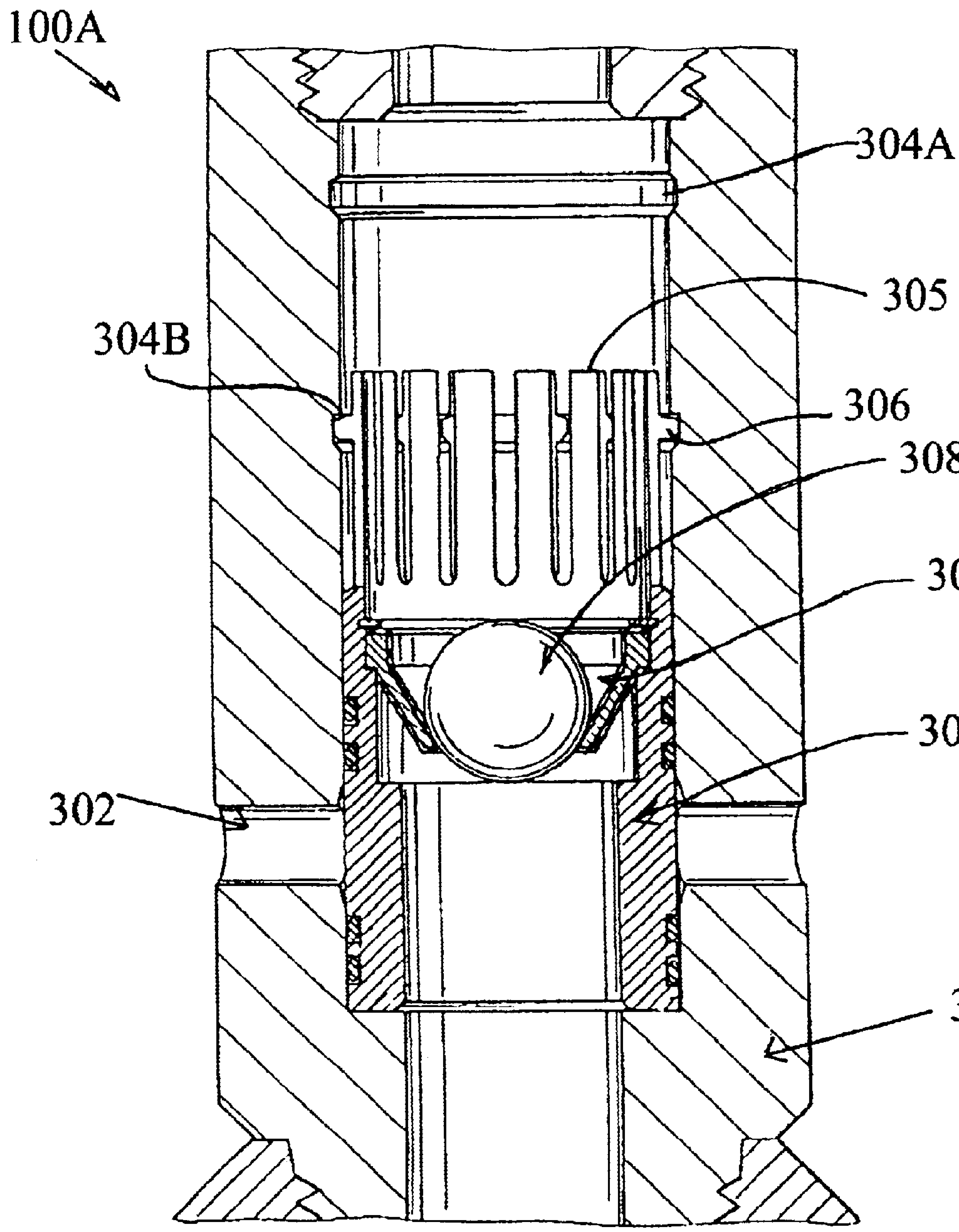


Fig. 5

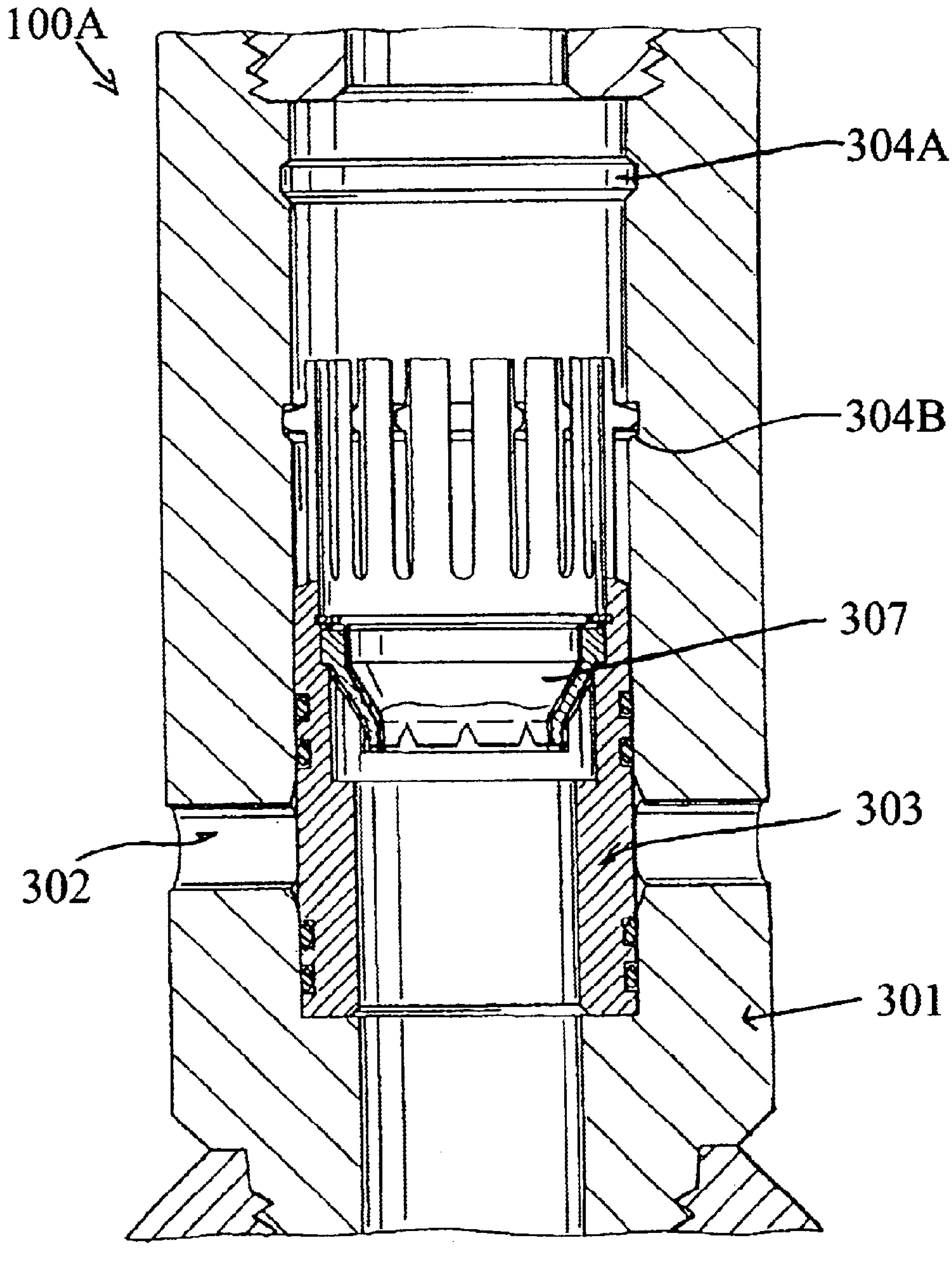
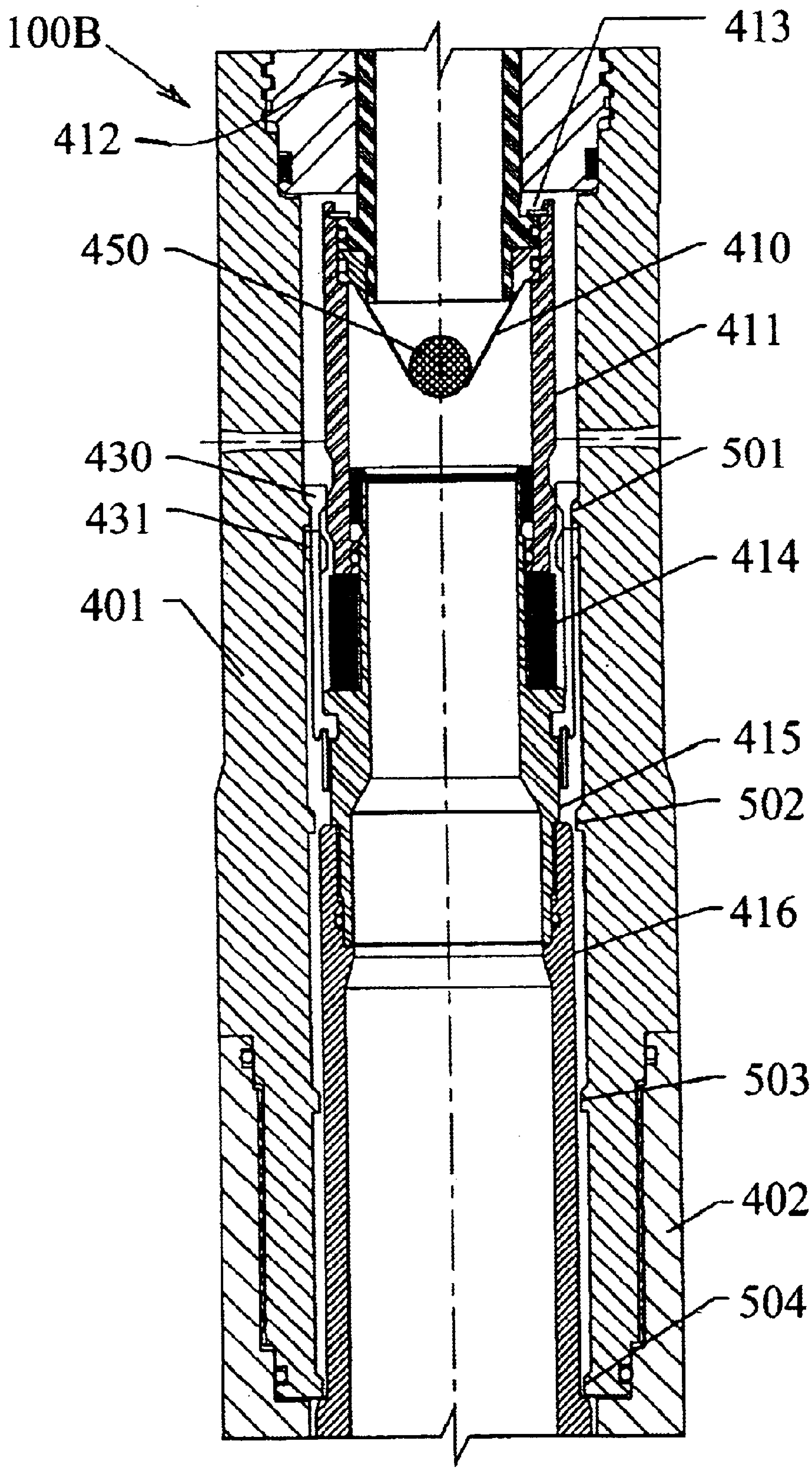


Fig. 6


100B
413
412
450
410
411
430
501
431
414
401
415
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416
503
402
504

Fig. 7

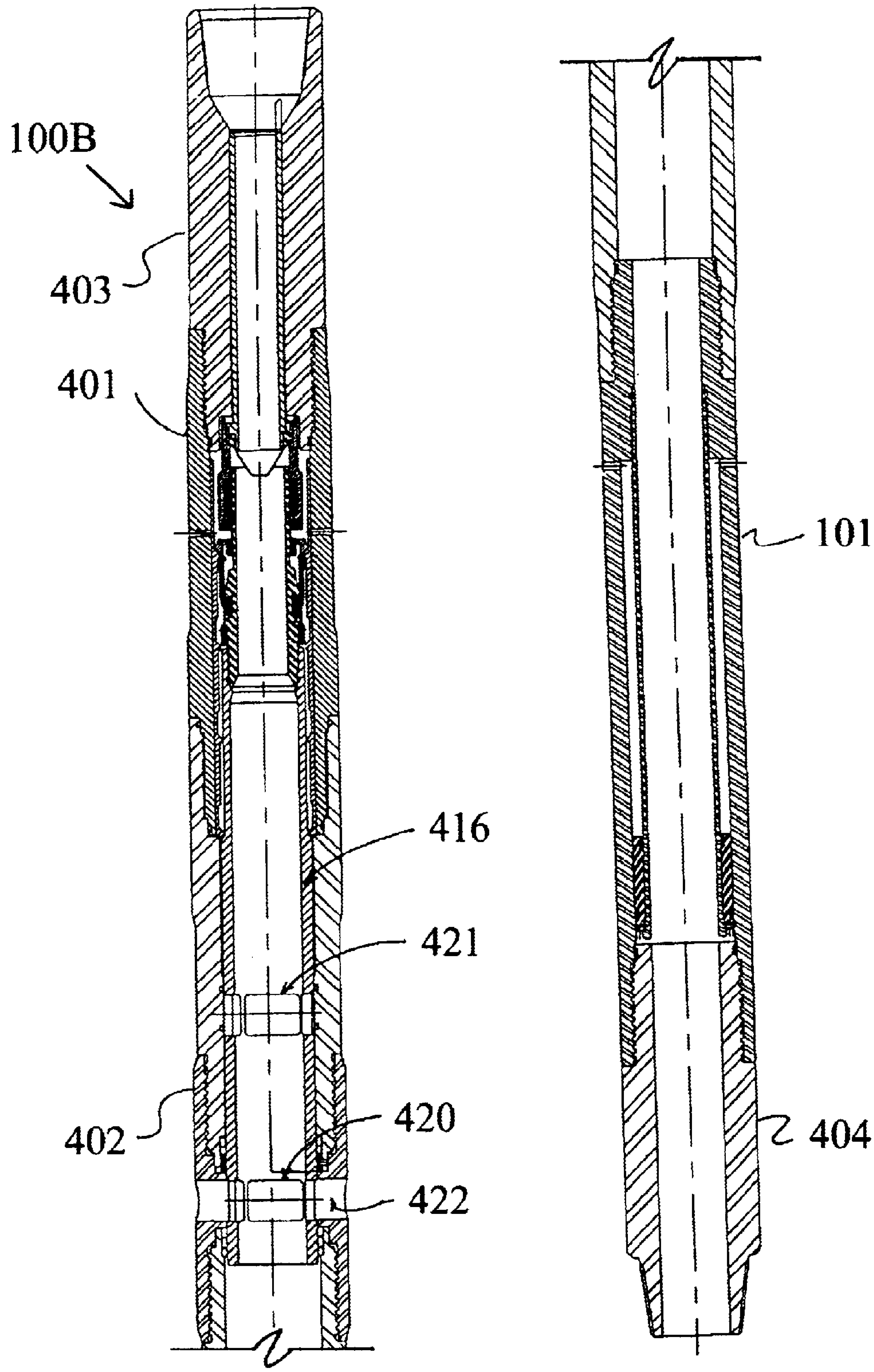

Fig. 8

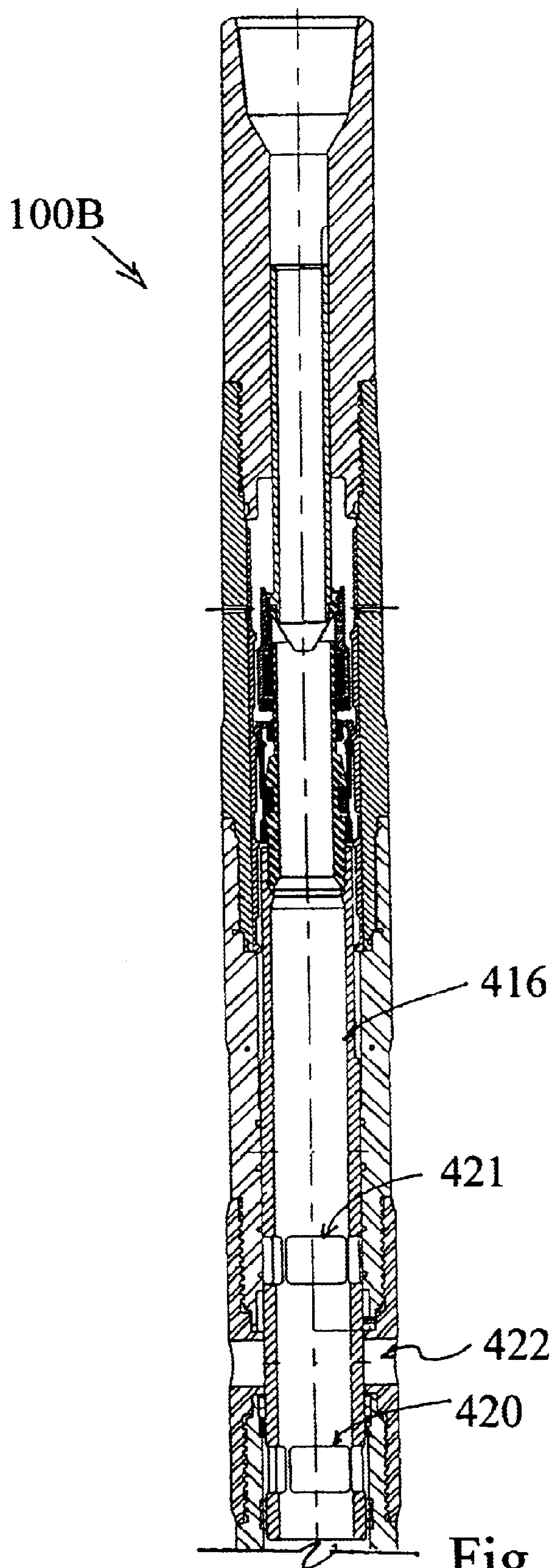

Fig. 9

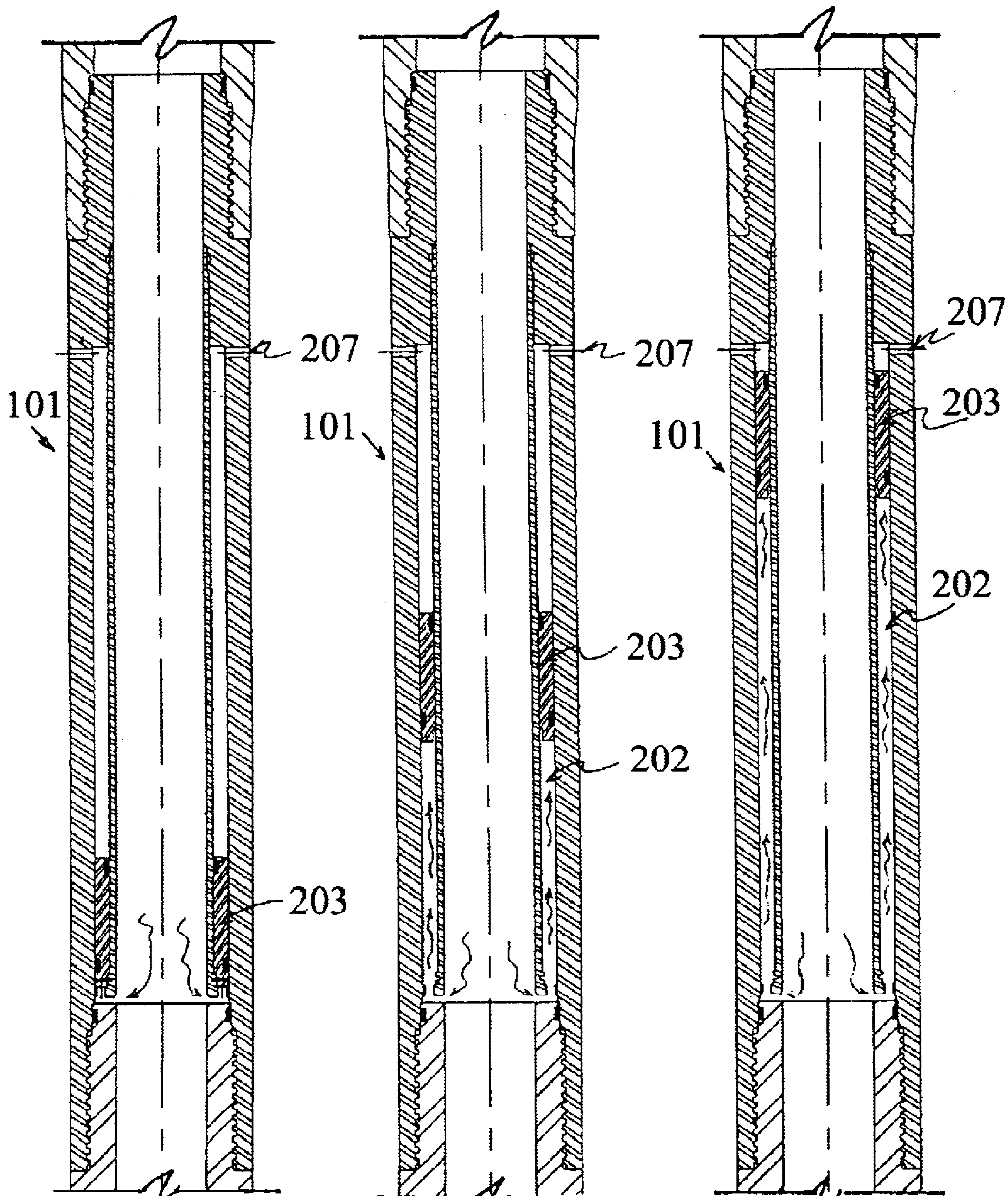

Fig. 10A Fig. 10B Fig. 10C

SURGE PRESSURE REDUCTION APPARATUS WITH VOLUME COMPENSATION SUB AND METHOD FOR USE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method and apparatus for providing surge pressure reduction functionality while running a drilling/production liner or sub-sea casing down a borehole.

2. Description of the Prior Art

The principle of operation of a surge pressure reduction tool is described in U.S. Pat. No. 5,960,881 ("the '881 patent"), which is incorporated herein by reference and which should be referred to with respect to the advantages provided by that invention.

The invention of the '881 patent has provided the oil well industry with the long-desired capability of running in a drilling/production liner or sub-sea casing faster and more reliably with a minimum of lost drilling fluid. Particularly, the surge pressure reduction tool comprises a housing assembly connected between a drill pipe and a drilling/production liner. The housing assembly includes a set of flow holes and an axial bore formed therein. A sliding sleeve resides within the axial bore of the housing assembly. When the sliding sleeve is positioned above the set of housing flow holes such that the sleeve does not block the flow holes, communication is established between the axial bore of the tool and the annulus between the tool and the borehole. This is called the "open port position" and is established to facilitate surge pressure reduction when running a drilling/production liner through drilling fluid down a borehole. When the sliding sleeve is displaced axially downward such that the set of flow holes of the housing assembly is blocked, communication is interrupted between the axial bore of the tool and the annulus between the tool and the borehole. This is called the "closed port position" and is established to provide circulation of drilling fluid downward through the tool and to the bottom of the drilling/production liner without short-circuiting the flow of drilling fluid through the flow holes of the housing assembly. Additionally, the housing assembly contains a yieldable ball seat attached to the sliding sleeve to receive a drop ball to facilitate shifting the sliding sleeve axially downward from the open port position to the closed port position.

In operation, a drilling/production liner is run down a borehole using a drill pipe and a surge pressure reduction tool attached between the drill pipe and the drilling/production liner. Initially, the tool is set in the open port position to provide surge pressure reduction functionality while the tool is being lowered through drilling fluid down the borehole. As the drilling/production liner is lowered in the open port position, the drilling fluid flows upward through the drilling/production liner, into the tool, and outward into the annulus between the tool and the borehole via the flow holes. However, if the drilling/production liner encounters a tight hole or bridge condition within the borehole, then it is not possible to effectively circulate drilling fluid around the end of the drilling/production liner to help free it because the flow holes of the tool will short-circuit the flow of drilling fluid to the annulus outside the tool. Therefore, a drop ball is released into the drill pipe to land in the yieldable ball seat thereby effectively sealing the sliding sleeve. Drilling fluid pressure is then increased above the drop ball to shift the sliding sleeve axially downward into the closed port position. Drilling pressure is once again increased above the drop ball to push the ball through the yieldable ball seat and out of the bottom of the drilling/production liner. Drilling fluid can then be circulated from the drill pipe, past the surge pressure reduction tool, and through the drilling/production liner to free the drilling/production liner from the tight hole condition. Once the drilling/production liner is free, lowering of the drilling/production liner is continued until it reaches total depth.

At total depth, the surge pressure reduction tool must be in the closed port position to facilitate hanging and cementing operations. Therefore, if the drilling/production liner is run downhole without encountering a tight hole condition requiring the benefits of circulation, then the tool must be shifted to the closed port position once total depth is reached.

While the invention of the '881 patent provides the oil well industry with much desired surge pressure reduction functionality, it only provides a single sequence of surge pressure reduction functionality per trip downhole. Therefore, once the tool has been shifted to the closed port position to facilitate circulation of drilling fluid to free the drilling/production liner from a tight hole condition, the drilling/production liner must be lowered the remainder of the trip to total depth without the benefits of surge pressure reduction.

Accordingly, a multi-function surge pressure reduction tool may be used to provide an additional sequence of surge pressure reduction per trip downhole. The principle of operation of a multi-function surge pressure reduction tool is described in U.S. application Ser. No. 09/812,522 ("the '522 application"), which is incorporated herein by reference and which should be referred to with respect to the advantages provided by that invention. The multi-function surge pressure reduction tool in accordance with the '522 application includes a housing assembly with a set of flow holes formed therein and a valving sleeve with two sets of flow ports formed therein at different axial locations. When the set of flow holes of the housing assembly is aligned with either set of flow ports of the valving sleeve, the tool is in an open port position. When the set of flow holes of the housing assembly is not aligned with either set of flow ports of the valving sleeve, the tool is in a closed port position. Since the valving sleeve has two sets of flow ports, the tool can be shifted from a first open port position to a first closed port position, from the first closed port position to a second open port position, and from the second open port position to a second closed port position. Therefore, if the drilling/production liner being lowered downhole using the multi-function surge pressure reduction tool encounters a tight hole condition, the valving sleeve is shifted from the first open port position to the first closed port position. This permits circulation of drilling fluid to free the drilling/production liner from the tight hole condition. Then, the valving sleeve is shifted to the second open port position to provide surge pressure reduction functionality to the drilling/production liner for the remainder of the trip to total depth. Once the drilling/production liner reaches total depth, the valving sleeve is shifted downward to the second closed port position such that hanging and cementing operations may be commenced.

While the surge pressure reduction tool of the '881 patent and the multi-function surge pressure reduction tool of the '522 application provide a mechanism having surge pressure reduction functionality, it has been observed that circumstances may be encountered during the running downhole of a drilling/production liner where a tool in accordance with the '881 patent or the '522 application may be rendered ineffective to facilitate circulation and cementing operations. Particularly, if a drilling/production liner, while being lowered down the borehole, becomes plugged with drill cuttings and debris that were created and left in the borehole during drilling operations, then it may not be possible to shift the sliding sleeve downward into the closed port position. Therefore, with the sliding sleeve unable to shift out of the open port position, cementing operations can not be performed at total depth and circulation operations can not be performed if the drilling/production liner encounters a tight hole condition. This is due to a pressure build-up in the drilling fluid trapped between the yieldable ball seat sealed by the drop ball and the debris blocking the drilling/production liner. This pressure build-up causes a hydraulic lock condition in which the trapped drilling fluid resists the force exerted above the drop ball to shift the sliding sleeve axially downward. Therefore, the tool cannot be shifted out of the open port position and communication between the surface and the drilling/production liner via the drill pipe is short-circuited by the open flow ports of the tool.

Accordingly, the oil well industry would find desirable a surge pressure reduction tool that can be shifted to the open port position to provide surge pressure reduction and to the closed port position to facilitate cementing operations and circulation of drilling fluid even in the event that the drilling/production liner becomes plugged with drill cuttings or downhole debris.

SUMMARY OF THE INVENTION

In accordance with the present invention, a method and apparatus for reducing surge pressure while running a tubular member on a drill pipe with a running tool through drilling fluid down a borehole using a drilling rig is provided.

Apparatus in accordance with the present invention includes a diverter device having a housing assembly with a set of flow holes formed therein. The housing assembly is suspended from a drill pipe such that the drill pipe provides a communication conduit between the drilling rig on the surface and the borehole. The diverter device also includes a sliding sleeve positioned within the housing assembly. When the set of flow holes of the housing assembly is not blocked by the sleeve, the tool is in an "open port position." When the set of flow holes of the housing assembly is blocked by the sleeve, the tool is in a "closed port position."

Apparatus in accordance with the present invention also includes a volume compensation device connected between the drilling/production liner and the diverter device. The volume compensation device, when activated, accumulates a volume of drilling fluid which is equal to or greater than the volume of drilling fluid displaced when the sliding sleeve moves from the open port position to the closed position.

In a preferred embodiment, the volume compensation device includes a housing having an upper end and a lower end and an axial bore formed therethrough. Additionally, the housing includes a set of annulus flow ports formed therein near the upper end. The volume compensation device also includes an inner sleeve having an upper end and a lower end, and an outer diameter smaller than the diameter of the axial bore of the housing. The total length of the inner sleeve is less than the length of the axial bore of the housing. The inner sleeve is arranged within the axial bore of the housing, and the upper end of the inner sleeve is attached to the upper end of the housing to form an annulus between the inner sleeve and the housing. An annular piston having an inner diameter approximately equal to the outer diameter of the sleeve and an outer diameter approximately equal to the diameter of the axial bore of the housing is attached to the lower end of the sleeve by at least one shear pin. If the drilling/production liner becomes plugged with drill cuttings or downhole debris, then trapped drilling fluid pressure within the volume compensation plug applies an upward force against the annular piston such that the set of shear pins shear and the annular piston moves axially upward. This provides the apparatus of the present invention with additional volume as required to shift the diverter device to the closed port position.

Furthermore, in the closed port position, apparatus in accordance with the present invention provides a flow path for drilling fluid to flow downward from the drill pipe to the diverter device, from the diverter device to the volume compensation device, from the volume compensation device to the running tool, from the running tool to the tubular member, and from the tubular member out into the borehole. Providing this flow path facilitates circulation and cementing operations.

Still furthermore, in the open port position, apparatus in accordance with the present invention provides an alternative flow path for drilling fluid to flow upward from the borehole into the tubular member, from the tubular member to the running tool, from the running tool to the volume compensation device, from the volume compensation device to the diverter device, and from the diverter device out into an annulus between the drill pipe and the borehole via the set of housing flow holes. Providing this flow path facilitates surge pressure reduction when lowering the tubular member downhole through drilling fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. **1** is an elevation view of a wellbore depicting a drilling/production liner being run downhole on a drill pipe.

FIG. **2** is a sectional view of a volume compensation device in accordance with the present invention.

FIG. **3** is an enlarged view of the volume compensation device of FIG. **2**.

FIG. **4** is an elevation view of a first embodiment of a surge pressure reduction tool having a single sequence of surge pressure reduction functionality.

FIG. **5** is an elevation view of a first embodiment of a surge pressure reduction tool having a single sequence of surge pressure reduction functionality in the open port position.

FIG. **6** is an elevation view of a first embodiment of a surge pressure reduction tool having a single sequence of surge pressure reduction functionality in the closed port position.

FIG. **7** is an enlarged view of an indexing apparatus of a second embodiment of a surge pressure reduction tool having multiple sequences of surge pressure reduction functionality in the open port position.

FIG. **8** is an elevation view of a second embodiment of a surge pressure reduction tool having multiple sequences of surge pressure reduction functionality in the open port position.

FIG. **9** is an elevation view of a second embodiment of a surge pressure reduction tool having multiple sequences of surge pressure reduction functionality in the closed port position.

FIG. **10**A is an enlarged view of a preferred embodiment of a volume compensation device in accordance with the present invention depicting an annular piston connected to an inner sleeve by a shear pin.

FIG. **10**B is an enlarged view of a preferred embodiment of a volume compensation device in accordance with the present invention depicting the annular piston moving axially upward after being released from the shear pin connection with the inner sleeve.

FIG. **10**C is an enlarged view of a preferred embodiment of a volume compensation device in accordance with the present invention depicting the annular piston moving axially upward and approaching fter being released from the shear pin connection with the inner sleeve.

DESCRIPTION OF SPECIFIC EMBODIMENT

In oilfield applications, a "drilling/production liner" and a "sub-sea casing" are tubular members which are run on drill pipe. The term "sub-sea casing" is used with respect to offshore drilling operations, while the term "drilling/production liner" is used with respect to both land and offshore drilling operations. For ease of reference in this specification, the present invention is described with respect to a "drilling/production liner." In the appended claims, the term "tubular member" is intended to embrace either a "drilling/production liner" or a "sub-sea casing." Additionally, the term "operatively connected" is used to mean "in direct connection with" or "in connection with via another element."

A description of a preferred embodiment of the present invention is provided to facilitate an understanding of the invention. This description is intended to be illustrative and not limiting of the present invention.

With reference first to FIG. **1**, the general components of a system in which a tool in accordance with the present invention is used are illustrated. A mast M suspends a traveling block TB. The traveling block TB supports a top drive D which moves vertically on a block dolly BD. An influent drilling fluid line L supplies the top drive D with drilling fluid from a drilling fluid reservoir (not shown). A launching manifold LM connects to a drill string S. The drill string S comprises a plurality of drill pipe segments which extend down into a borehole BH, and the number of such pipes is dependent on the depth of the borehole BH. A diverter device **100** and volume compensation device **101** in accordance with the present invention are connected between the bottom end of drill string S and the top of running tool **102**. The running tool **102** is preferably a casing hanger. A drilling/production liner **103** is suspended from the running tool **102**. An open guide shoe **104** is fastened to the bottom of the drilling/production liner **103**.

Still with reference to FIG. **1**, solidified cement CE**1** fixes a surface casing SC to surrounding formation F. The surface casing SC contains an opening O in the uppermost region of the casing adjacent to the top. The opening O controls return of drilling fluid as it travels up the annulus between the drill string S and the surface casing SC. Additionally, solidified cement CE**2** fixes an intermediate casing IC to the surrounding formation F. The intermediate casing IC is hung from the downhole end of the surface casing SC by a mechanical or hydraulic hanger H.

Still further with reference to FIG. **1**, a preferred embodiment of the present invention includes a diverter device **100** having an upper end an a lower end. The upper end of the diverter device **100** is operatively connected to the drill string S. The lower end of the diverter device **100** is operatively connected to a volume compensation device **101**. The volume compensation device **101** is operatively connected to a drilling/production liner **103** via a running tool **102**.

With reference to FIGS. **2** and **3**, a preferred embodiment of the volume compensation device **101** in accordance with the present invention includes a housing **200** having an upper end and a lower end and an axial bore formed therethrough. The volume compensation device **101** further includes an inner sleeve **201** with an upper end and a lower end and having an outer diameter smaller than the diameter of the axial bore of the housing **200**. The total length of the inner sleeve **201** is less than the length of the inner bore of the housing **200**. The inner sleeve **201** is arranged withing the housing **200** and the upper end of the sleeve is attached to the upper end of the housing to form a compensation volume annulus **202** between the inner sleeve and the housing. An annular piston **203** having an inner diameter approximately equal to the outer diameter of the inner sleeve **201** and an outer diameter approximately equal to the diameter of the axial bore of the housing **200** is attached to the lower end of the sleeve by a set of one or more shear pins **204**. The annular piston **203** includes an inner seal **205** for sealing with the outer wall of the inner sleeve **201** and an outer seal **206** for sealing with the axial bore of the housing **200**. The inner seal **205** and the outer seal **206** are preferably O-rings. The housing **200** also has at least one annulus hole **207** formed therein near the upper end to establish communication between the compensation volume annulus **202** and the borehole BH (FIG. **1**).

With reference to FIG. **4**, a first embodiment of the present invention includes a diverter device **100**A having a single sequence of surge pressure reduction functionality. The diverter device **100**A comprises a housing assembly **301** having an upper end, a lower end, and an axial bore therethrough. The upper end of the housing assembly **301** is operatively connected to a drill string S. The lower end of the housing assembly **301** is operatively connected to a volume compensation device **101** (FIG. **2**). The housing assembly **301** includes a set of flow holes **302** formed therein for establishing communication between the annulus outside the diverter device **100**A and the axial bore. The axial bore of the housing assembly **301** includes an upper circumferential groove **304**A and a lower circumferential groove **304**B formed therein.

Still with reference to FIG. **4**, a sleeve **303** having an upper end and a lower end is arranged within the axial bore of the housing **301**. A plurality of latching fingers **305** are formed on the upper end of the sleeve **303**. Each of the latching fingers **305** has a shoulder **306** formed on its end protruding radially outward for engagement with the circumferential grooves **304**A and **304**B of the housing assembly **301**. When the shoulder **306** of each latching finger **305** engages the upper circumferential groove **304**A such that the lower end of the sleeve **303** does not block the housing flow holes **302**, the diverter device **100**A is in an "open port position." In the open port position, communication is established between the axial bore of the housing assembly **301** and the annulus outside the housing assembly. When the shoulder **306** of each latching finger **305** engages the lower circumferential groove **304**B and the lower end of the sleeve **303** blocks the housing flow holes **302**, the diverter device **101**A is in a "closed port position" (FIG. **6**). In the closed port position, communication between the axial bore of the housing assembly **301** and the annulus outside the housing assembly is interrupted.

With reference to FIGS. **4–6**, the diverter device **100**A further includes a yieldable ball seat **307** and a drop ball **308** for shifting the sleeve from the open port position to the closed port position.

With respect to FIGS. **1** and **4**, in operation, the diverter device **100**A is run into a borehole with the sleeve **303** positioned such that the shoulders **306** of the latching fingers **305** engage the upper circumferential groove **304**A. In this "open port position," a flow path exists for drilling fluid to flow upward from the borehole BH into the drilling/production liner **103**, through the volume compensation device **101** and diverter device **100**A, and outward to the annulus between the drill string S and surface casing C**2** via the set of housing flow holes **302**.

The drilling/production liner **103** is run into the borehole with the diverter device **100**A in the open port position and thus the benefits of surge pressure reduction are realized. However, if the drilling/production liner **103** encounters a tight hole condition within the borehole BH, then circulation is required to free the drilling/production liner, and the diverter device **100**A must be moved to the closed port position.

With reference to FIG. **5**, the diverter device **100**A is shifted to the closed port position by releasing the drop ball **308** down the drill string S and into the yieldable ball seat **307**. Drilling fluid pressure is then increased above the drop ball **308** and the yieldable ball seat **307** to a first predetermined level which forces the shoulders **306** of the latching fingers **305** radially inward. The inward radial motion of the shoulders **306** releases the latching fingers **305** and the sleeve **303** moves axially downward. The downward movement of the sleeve **303** is arrested when the shoulders **306** of the latching fingers **305** engage the lower circumferential groove **304**B, and the diverter device **100**A is now in the closed port position.

With reference to FIGS. **1** and **6**, once in the closed port position, the drilling fluid pressure is increased to a predetermined level above the drop ball **308** to force the drop ball through the yieldable ball seat **307**. In this "closed port position," a flow path exists for drilling fluid to flow downward from the drill string S, through the diverter device **100**A and volume compensation sub **101**, and outward into the borehole BH via the drilling/production liner **103**.

With reference to FIGS. **7** and **8**, a second embodiment of the present invention includes a diverter device **100**B having multiple sequences of surge pressure reduction functionality. The diverter device **100**B comprises a housing assembly with an upper housing **401** and a lower housing **402** which are in threaded engagement with one another. The upper housing **401** is in threaded engagement with a top sub **403**, and the lower housing **402** is in threaded engagement with a volume compensation device **101**. The volume compensation device **101** is in threaded connection with a bottom sub **404**. The top sub is operatively connected to the drill string S (FIG. **1**). The bottom sub is operatively connected to the drilling/production liner **103** via running tool **102** (FIG. **1**).

With reference to FIGS. **7–9**, the housing assembly **401**, **402** contains a yieldable ball seat **410** connected to a camming sleeve **411**. The lower end of a dart directing sleeve **412** is connected to the yieldable ball seat **410**, and a snap ring **413** is utilized to secure the yieldable ball seat and dart directing sleeve in place on the upper end of the camming sleeve **411**. The camming sleeve **411** is supported by spring washers **414**. The spring washers **414** are in turn supported on a threaded sleeve **415** that is connected with the top of a valving sleeve **416**. At least two sets of axially spaced sleeve flow ports **420**, **421** are formed in the valving sleeve **416**. Additionally, a set of housing flow holes **422** is formed in the lower housing **402**. As explained below, the valving sleeve **416** is indexed axially downward in the operation of a diverter device **100**B in accordance with the present invention. Initially, the axial position of valving sleeve **416** is such that the set of sleeve flow ports **420** is aligned with the set of housing flow holes **422**. When the axial position of the valving sleeve **416** is such that a set of sleeve flow ports **420**, **421** is aligned with the set of housing flow holes **422**, diverter device **100**B is in an "open port position" (FIG. **8**). When the axial position of the valving sleeve **416** is such that no set of sleeve flow ports **420**, **421** is aligned with the set of housing flow holes **422**, the diverter device **100**B is in a "closed port position" (FIG. **9**).

With reference to FIG. **7**, the apparatus in accordance with the present invention further includes an indexing mechanism to shift the diverter device **100**B between the open port position and the closed port position. The indexing mechanism is contained within the upper housing **401** and has four latch positions **501**, **502**, **503**, **504** designed to support axially downward indexing. Axially spaced internal protrusions or "rings" at positions **501**, **502**, **503**, **504** are machined in the bore of the upper housing **401** that contains the latching mechanism. The axial spacing of these machined rings determines the specific position of the indexing mechanism at any given time. The rings are engaged by an assembly of pivoting latching fingers **430**, **431**. One end of each latching finger **430**, **431** is attached to the threaded sleeve **415**. The assembly of latching fingers comprises both long fingers **430** and short fingers **431**. The short fingers **431** are evenly interspersed among the long fingers **430** such that every other finger is a short finger. Each latching finger **430**, **431** includes an external shoulder that rests on the internal machined indexing rings of the housing while also including an internal protrusion that interacts with the camming sleeve **411** so that the camming sleeve alternately forces the short or long latching fingers radially outward.

Still with reference to FIG. **7**, the short and long latching fingers **430**, **431** are initially positioned to span across the top machined internal ring **501**. The camming sleeve **411** is supported in the uppermost position by the spring washers **414** until a drop ball **450** lands in the yieldable ball seat **410**. With the camming sleeve **411** in the uppermost position, the long latching fingers **430** are forced radially outward and thus the internal ring **501** of the housing restrains the indexing assembly from moving downward.

In operation, the diverter device **100**B in accordance with the present invention provides for the running, hanging, and cementing of a drilling/production liner downhole in a single running.

With reference to FIGS. **1**, **7**, and **8**, the diverter device **100**B is run into a borehole BH with the camming sleeve **411** and valving sleeve **416** positioned such that the long latching fingers **430** are caught on the top face of the uppermost housing ring at latch position **501**. In this position, the short fingers **431** are positioned immediately below the uppermost housing ring at latch position **501**. In this "open port position," the set of sleeve flow ports **420** of valving sleeve **416** is aligned with the set of housing flow holes **422** and a flow path exists for drilling fluid to flow upward into the drilling/production liner **103** through the volume compensation device **101** and diverter device **100**B, and outward to the annulus between the drill string S and surface casing C**2** via aligned flow hole **422** and flow port **420**.

The drilling/production liner **103** is run into the borehole with the diverter device **100**B in the open port position and thus the benefits of surge pressure reduction are realized. However, if the drilling/production liner **103** encounters a tight hole condition within the borehole BH, then circulation is required to free the drilling/production liner, and the diverter device **100**B must be moved to the closed port position.

With reference to FIGS. **7** and **9**, the diverter device **100**B in accordance with the present invention is shifted to the closed port position by releasing a first drop ball **450** down the drill string S, through the dart directing sleeve **412**, and into the yieldable seat **410**. The drilling fluid pressure is then increased above the drop ball **450** and the yieldable ball seat **410** to a first predetermined level, which moves the yieldable ball seat and camming sleeve **411** from its initial axial position downward against the resistance of the spring washers **414** to a second axial position. This downward axial movement frees the radial restraint on the long latching fingers **430** while simultaneously forcing the short latching fingers **431** radially outward. The inward radial motion of the long latching fingers **430** releases the indexing assembly and allows it, and the valving sleeve **416**, to move axially downward. The simultaneous outward radial motion of the short latching fingers **431** provides an external protrusion that will catch the short fingers on the next lower ring at latch position **502**. The downward movement of the indexing assembly and attached valving sleeve is arrested at latch position **502** and the diverter device **100**B is now in the closed port position.

Still with reference to FIGS. **7** and **9**, once the indexing apparatus is shifted into the closed port position, the pressure above the first drop ball **450** is increased further to a predetermined level where the yieldable ball seat **410** yields to an extent that permits the first drop ball to pass through the yieldable ball seat and on down to the bottom of the borehole. Once the first drop ball **450** passes the yieldable ball seat **410** and the pressure is freed from the spring washers **414**, the spring washers reset and push the camming sleeve **411** slightly back up so that the short latching fingers **431** are free to move radially inward and the long fingers **431** are forced radially outward. The valving sleeve **416** then slips slightly downward so that the radially protruding long fingers **430** catch on the ring at latch position **502**.

With reference to FIGS. **1** and **9**, once the diverter device **100**B is in the first closed port position and circulation is established, drilling fluid can be pumped downward along a flow path from the surface, through the drill string S, diverter device **100**B, and volume compensation device **101**, and to the bottom of the drilling/production liner **103** (FIG. **1**) to free the drilling/production liner from the tight hole condition. Once the drilling/production liner **103** is free, downhole running operations can continue and surge pressure reduction can be reestablished by shifting the indexing apparatus into a second open port position using a second drop ball having a diameter greater than the diameter of the first drop ball. After the drilling/production liner is run to total depth, the indexing apparatus can be shifted downward into a second closed port position using a third drop ball having a diameter greater than the diameter of the second drop ball. In the second closed port position, cementing operations can be performed.

With respect to the two embodiments described above, if the passage through the drilling/production liner is obstructed by drill cuttings or downhole debris, then releasing a drop ball into the yieldable ball seat will effectively trap the drilling fluid between the yieldable ball seat and the plugged drilling/production liner. Therefore, when drilling fluid pressure is increased above the drop ball to shift the diverter device into the closed port position, the trapped drilling fluid will resist the downward shifting of the sleeve. This condition is called "hydraulic lock." In this hydraulic lock condition, the sleeve of the diverter tool can not be shifted axially downward to block the housing flow holes. With the housing flow holes unobstructed, circulation and, more significantly, critical cementing operations can not be performed. Therefore, the volume compensation device, once activated, accumulates enough of the trapped drilling fluid to permit the sleeve of the diverter device to be shifted axially downward. Once a sufficient volume of the resisting drilling fluid is removed, the hydraulic lock condition ends and the sleeve is moved to the closed port position.

With reference to FIGS. **2** and **3**, in operation, the volume compensation device **101** accumulates the trapped drilling fluid to enable the sleeve of the diverter device to shift to the closed port position. As the drilling fluid pressure above the drop ball is increased, the trapped drilling fluid beneath the drop ball forces the annular piston **203** upward against the restraint of the shear pins **204**. Once the force against the annular piston is sufficient to shear the shear pins **204**, the volume compensation device is activated and the annular piston **203** is released from the lower end of the inner sleeve **201**.

With reference to FIGS. **10**A, **10**B, and **10**C, once the annular piston **203** is released, the trapped drilling fluid forces the annular piston upwards. As the annular piston **203** moves upward, the drilling fluid fills the volume vacated by the rising piston. As the drilling fluid pressure above the drop ball forces the sleeve of the diverter device to move axially downward, the trapped drilling fluid reacts by forcing the annular piston **203** further upward filling in the vacated space below the piston until enough drilling fluid has been displaced to shift the sleeve into the closed port position.

Furthermore, as the annular piston **203** moves axially upward, it sweeps any fluid that has collected in the compensation volume annulus **202** outward into the borehole via a set of annulus holes **207**. It is also intended that the compensation volume annulus **202** above the annular piston may be filled with a preservative compound such as grease to prevent contamination of the compensation volume annulus as the surge pressure reduction tool is run downhole.

Once the sleeve is in the closed port position and the housing flow ports are blocked, drilling fluid pressure is increased above the drop ball to push the drop ball through the yieldable seat. Now a flow path is established through the diverter device such that drilling fluid can be pumped through the drilling/production liner to remove the plugged drill cuttings or downhole debris. Finally, with the diverter device in the closed port position, circulation can be performed if the drilling/production liner is in a tight hole condition or cementing operations can be commenced if the drilling/production liner is at total depth.

In the appended claims, the term "open port position" refers to a condition where the set of flow holes formed in the housing assembly of the diverter device is not blocked by a sleeve; and the term "closed port position" refers to a condition where the set of flow holes formed in the housing assembly of the diverter device is blocked by a sleeve in the diverter device. Furthermore, the term "plugged" refers to a condition where passage through the tubular member is obstructed by drill cuttings or downhole debris

What is claimed is:

1. Apparatus for use in reducing surge pressure while running a tubular member through a borehole containing drilling fluid using a drilling rig, said apparatus comprising:

a drill pipe for communication between the drilling rig and the borehole, said drill pipe comprising an upper end operatively connected to the drilling rig and a lower end,

a diverter device for directing flow of drilling fluid, said diverter device comprising: (i) a housing assembly having an upper end operatively connected to the lower end of the drill pipe and a lower end, said housing assembly having a set of flow holes formed therein; (ii) a sleeve within the housing assembly having an upper end and a lower end, said sleeve being movable between an open port position where the set of flow holes is not blocked by the sleeve and a closed port position where the set of flow holes is blocked by the sleeve; and (iii) means to shift the sleeve downward from an open port position to a closed port position, said means displacing a predetermined volume of drilling fluid to shift the sleeve downward from an open port position to a closed port position, and

a volume compensation device which, when activated, accumulates a volume of drilling fluid equal to or greater than the volume of drilling fluid which is displaced when the sleeve of the diverter device is shifted downward from an open port position to a closed port position, said volume compensation device having an upper end operatively connected to the diverter device and a lower end operatively connected to the tubular member.

2. Apparatus for use in reducing surge pressure while running a tubular member through a borehole containing drilling fluid using a drilling rig, said apparatus comprising:

a drill pipe for communication between the drilling rig and the borehole, said drill pipe comprising an upper end operatively connected to the drilling rig and a lower end,

a diverter device for directing flow of drilling fluid, said diverter device comprising: (i) a housing assembly having an upper end operatively connected to the lower end of the drill pipe and a lower end, said housing assembly having a set of flow holes formed therein; (ii) a sleeve within the housing assembly having an upper end and a lower end, said sleeve being movable between an open port position where the set of flow holes is not blocked by the sleeve and a closed port position where the set of flow holes is blocked by the sleeve; and (iii) means to shift the sleeve downward from an open port position to a closed port position, said means displacing a predetermined volume of drilling fluid to shift the sleeve downward from an open port position to a closed port position, and

a volume compensation device which, when activated, accumulates a volume of drilling fluid equal to or greater than the volume of drilling fluid which is displaced when the sleeve of the diverter device is shifted downward from an open port position to a closed port position, said volume compensation device having an upper end operatively connected to the diverter device and a lower end operatively connected to the tubular member,

wherein the volume compensation device comprises: (i) a housing with an upper end operatively connected to the lower end of the housing assembly of the diverter device, a lower end operatively connected to the tubular member, and an axial bore formed therethrough, said housing having at least one flow hole formed near the upper end to establish communication between the axial bore of the housing and the borehole; (ii) an inner sleeve positioned inside the housing with a total axial length less than the total length of the axial bore of the housing, said inner sleeve having an outer diameter smaller than the diameter of the axial bore of the housing to form an annulus between the housing and the inner sleeve; (iii) a piston having an inner diameter approximately equal to the outer diameter of the inner sleeve and an outer diameter approximately equal to the diameter of the axial bore of the housing; and (iv) means to attach the piston to the inner sleeve near the lower end of the housing.

3. The apparatus of claim **2**, wherein the means to attach the piston to the inner sleeve is a set of shear pins.

4. The apparatus of claim **2**, wherein the piston further comprises an inner seal to engage the inner sleeve and an outer seal to engage the axial bore of the housing.

5. The apparatus of claim **2**, wherein the sleeve of the diverter device is initially in the open port position when lowered into the borehole.

6. The apparatus of claim **5**, further comprising:

an upper circumferential groove formed in the housing assembly of the diverter device;

a lower circumferential groove formed in the housing assembly of the diverter device;

a plurality of latching fingers formed on the upper end of the sleeve, each of said latching fingers having a shoulder protruding radially outward for engagement with the upper circumferential groove when the sleeve is in the open port position and the lower circumferential groove when the sleeve is in the closed port position.

7. The apparatus of claim **6**, further comprising:

a yieldable ball seat attached to the sleeve of the diverter device, said yieldable ball seat movable between a sealing position and a yielding position; and

a ball which is dropped down the drill pipe and which seats in the yieldable ball seat.

8. The apparatus of claim **7**, further comprising:

means for establishing a first pressure above the ball to release the latching fingers from engagement with the upper circumferential groove and move the sleeve downward until the latching fingers engage the lower circumferential groove thereby moving the sleeve from the open port position to the closed port position; and

means for establishing a second pressure above the ball to force the ball through the yieldable ball seat.

9. The apparatus of claim **7**, further comprising:

means for establishing a first pressure above the ball to release the latching fingers from engagement with the upper circumferential groove;

means for establishing a second pressure above the ball to detach the piston from the lower end of the inner sleeve of the volume compensation device and force the piston axially upward to provide volume for the sleeve of the diverter device to move downward until the latching fingers engage the lower circumferential groove thereby moving the sleeve from the open port position to the closed port position; and

means for establishing a third pressure above the ball to force the ball through the yieldable ball seat.

10. The apparatus of claim **2**, wherein the sleeve of the diverter device is a valving sleeve comprising two sets of flow ports formed therein at axially spaced locations, and the valving sleeve is initially in a first open port position when lowered into the borehole.

11. The apparatus of claim 10, further comprising:

a plurality of protrusions formed in the housing assembly of the diverter device at axially spaced locations;

a plurality of latching fingers having first and second ends, the first ends of said latching fingers being attached to the threaded sleeve and the second ends of said latching fingers being formed to engage the protrusions in the housing assembly, some of the latching fingers having a length which is longer than the length of the remainder of the latching fingers;

spring washers which are supported by the threaded sleeve; and

a camming sleeve including a yieldable ball seat, which camming sleeve is supported by the spring washers and movable from a first axial position to a second axial position, where the camming sleeve in said first axial position contacts the second ends of the longer latching fingers to force them into engagement with one of the protrusions in the housing assembly and where the movement of the camming sleeve to the second axial position releases the longer latching fingers from engagement with the protrusion and forces the second ends of the shorter latching fingers into contact with the inside of the housing assembly.

12. The apparatus of claim 11, further comprising:

a first ball which is dropped down the drill pipe and which seats in the yieldable ball seat;

means for establishing a first pressure above the first ball which is sufficient to move the camming sleeve from its first axial position to its second axial position and to move the valving sleeve from the first open port position to a first closed port position;

means for establishing a second pressure above the first ball which is sufficient to force the first ball through the yieldable ball seat.

13. The apparatus of claim 12, further comprising:

a second ball which is dropped down the drill pipe and which seats in the yieldable ball seat, said second ball having a larger diameter than said first ball;

means for establishing a first pressure above the second ball which is sufficient to move the camming sleeve from its first axial position to its second axial position and to move the valving sleeve from the first closed port position to a second open port position; and

means for establishing a second pressure above the second ball which is sufficient to force the second ball through the yieldable ball seat.

14. The apparatus of claim 13, further comprising:

a third ball which is dropped down the drill string and which seats in said yieldable ball seat, said third ball having a larger diameter than said second ball;

means for establishing a first pressure above the third ball which is sufficient to move the camming sleeve from its first axial position to its second axial position and to move the valving sleeve from the second open port position to a second closed port position; and

means for establishing a second pressure above the third ball which is sufficient to force the third ball through the yieldable ball seat.

15. The apparatus of claim 13, wherein communication through the tubular member is interrupted, further comprising:

a third ball which is dropped down the drill string and which seats in said yieldable ball seat, said third ball having a larger diameter than said second ball;

means for establishing a first pressure above the third ball which is sufficient to move the camming sleeve from its first axial position to its second axial position;

means for establishing a second pressure above the third ball to release the piston from the lower end of the inner sleeve of the volume compensation device and force the piston axially upward to provide volume for the valving sleeve of the diverter device to move downward from the second open port position to a second closed port position; and

means for establishing a third pressure above the third ball to force the third ball through the yieldable ball seat.

16. The apparatus of claim 11, further comprising:

a first ball which is dropped down the drill pipe and which seats in the yieldable ball seat;

means for establishing a first pressure above the first ball which is sufficient to move the camming sleeve from its first axial position to its second axial position

means for establishing a second pressure above the first ball to release the piston from the lower end of the inner sleeve of the volume compensation device and force the piston axially upward to provide volume for the valving sleeve of the diverter device to move downward from the first open port position to a first closed port position; and

means for establishing a third pressure above the first ball to force the first ball through the yieldable ball seat.

17. A method for reducing surge pressure while running in a tubular member on a drill pipe with a running tool through a borehole containing drilling fluid using a drilling rig, comprising:

providing a diverter tool between the drill pipe and the tubular member which establishes a flow path for drilling fluid to flow upward from the borehole into the tubular member, from the tubular member to the running tool, from the running tool to the diverter tool, and from the diverter tool into an annulus between the drill pipe and the borehole;

shifting the diverter tool to alter the flow path for drilling fluid to flow downward from the drilling rig to the drill pipe, from the drill pipe to the diverter tool, from the diverter tool to the running tool, from the running tool to the tubular member, and from the tubular member into the borehole; said shifting step displacing a predetermined volume of drilling fluid; and

providing a device between the diverter tool and the running tool which device, when activated, accumulates a volume of drilling fluid equal to or greater than the volume of drilling fluid which is displaced by the shifting step.

18. A method for reducing surge pressure while running in a tubular member on a drill pipe through a borehole containing drilling fluid using a drilling rig, comprising:

operatively connecting a diverter device between the drill pipe and the tubular member, said diverter device including (i) a housing assembly with a set of flow holes formed therein, (ii) a sleeve that can be moved between an open port position where the set of flow holes is not blocked by the sleeve and a closed port position where the set of flow holes is blocked by the sleeve, and (iii) means for shifting the sleeve downward from an open port position to a closed port position displacing a predetermined volume of drilling fluid; and

operatively connecting a volume compensation device between the diverter device and the tubular member, said volume compensation device providing a volume to the diverter device equal to or greater than the volume used to shift the sleeve downward from an open port position to a closed port position.

19. A method for reducing surge pressure while running in a tubular member on a drill pipe through a borehole containing drilling fluid using a drilling rig, comprising:

operatively connecting a diverter device between the drill pipe and the tubular member, said diverter device including (i) a housing assembly with a set of flow holes formed therein, (ii) a sleeve that can be moved between an open port position where the set of flow holes is not blocked by the sleeve and a closed port position where the set of flow holes is blocked by the sleeve, and (iii) means for shifting the sleeve downward front an open port position to a closed port position displacing a predetermined volume of drilling fluid; and

operatively connecting a volume compensation device between the diverter device and the tubular member, said volume compensation device providing a volume to the diverter device equal to or greater than the volume used to shift the sleeve downward from an open port position to a closed port position,

wherein the means for shifting the sleeve includes a yieldable ball seat attached to the sleeve and the volume compensation device includes: (i) a housing having an upper end, a lower end, and at least one flow port formed near the upper end; (ii) an inner sleeve within the housing having an upper end and a lower end and forming an annulus between the housing and the inner sleeve; and (iii) a piston arranged within the annulus and initially attached to the lower end of the inner sleeve by a set of shear pins.

20. The method of claim **19**, further comprising the steps of:

lowering the tubular member into the borehole with the sleeve of the diverter device initially in the open port position; and

moving the sleeve of the diverter device downward from the initial open port position to the closed port position.

21. The method of claim **20** wherein the step of lowering the tubular member into the borehole with the sleeve in the open port position further comprises:

providing a flow path for drilling fluid to flow upward into the tubular member, through the volume compensation device and the diverter device, and outward into an annulus between the drill pipe and the borehole via the set of flow holes.

22. The method of claim **20** wherein the step of moving the sleeve of the diverter device downward to the closed port position further comprises:

providing a flow path for drilling fluid to flow downward through the drill pipe, past the diverter device and the volume compensation device, and outward into the borehole via the tubular member.

23. The method of claim **20**, wherein the step of moving the sleeve downward comprises the steps of:

dropping a ball into the yieldable ball seat, said ball sealing with the yieldable ball seat;

increasing drilling fluid pressure to a first predetermined level above the ball and against the sleeve to move the sleeve axially downward from the open port position to the closed port position; and

further increasing drilling fluid pressure to a second predetermined level above the ball to expand the yieldable ball seat to allow the ball to pass through the yieldable ball seat.

24. The method of claim **20**, wherein the step of moving the sleeve downward comprises the steps of:

dropping a ball into the yieldable ball seat, said ball sealing with the yieldable ball seat;

increasing drilling fluid pressure to a first predetermined level above the ball to detach the piston from the lower end of the inner sleeve of the volume compensation device and force the piston axially upward to provide volume for the sleeve of the diverter device to move downward from the open port position to the closed port position; and

further increasing drilling fluid pressure to a second predetermined level above the ball to expand the yieldable ball seat to allow the ball to pass through the yieldable ball seat.

25. A method for reducing surge pressure while running in a tubular member on a drill pipe through a borehole containing drilling fluid using a drilling rig, comprising:

operatively connecting a diverter device between the drill pipe and the tubular member, said diverter device including (i) a housing assembly with a set of flow holes formed therein, (ii) a sleeve that can be moved between an open port position where the set of flow holes is not blocked by the sleeve and a closed port position where the set of flow holes is blocked by the sleeve, and (iii) means for shifting the sleeve downward from an open port position to a closed port position displacing a predetermined volume of drilling fluid; and

operatively connecting a volume compensation device between the diverter device and the tubular member, said volume compensation device providing a volume to the diverter device equal to or greater than the volume used to shift the sleeve downward from an open port position to a closed port position,

wherein the sleeve of the diverted device is a valving sleeve having an upper end, a lower end, and two sets of flow ports formed therein at axially spaced locations, said valving sleeve initially being in a first open port position.

26. The method of claim **25**, wherein the diverter device includes: (i) a plurality of protrusions formed in the housing assembly at axially spaced locations; (ii) a threaded sleeve operatively connected to the upper end of the valving sleeve; (iii) a plurality of latching fingers having first and second ends, the first ends of said latching fingers being attached to the threaded sleeve and the second ends of said latching fingers being formed to engage the protrusions in the housing assembly, some of the latching fingers having a length which is longer than the length of the remainder of the latching fingers; (iv) spring washers which are supported by the threaded sleeve; and (v) a camming sleeve including a yieldable ball seat, which camming sleeve is supported by the spring washers and movable from a first axial position to a second axial position, where the camming sleeve in said first axial position contacts the second ends of the longer latching fingers to force them into engagement with one of the protrusions in the housing assembly and where the movement of the camming sleeve to the second axial position releases the longer latching fingers from engagement with the protrusion and forces the second ends of the shorter latching fingers into contact with the inside of the housing assembly.

27. The method of claim **26**, wherein the volume compensation device includes: (i) a housing having an upper end, a lower end, and at least one flow port formed near the upper end; (ii) an inner sleeve within the housing having an upper end and a lower end and forming an annulus between the housing and the inner sleeve; and (iii) a piston arranged within the annulus and initially attached to the lower end of the inner sleeve by a set of shear pins.

28. The method of claim **27**, further comprising the steps of:

lowering the tubular member into the borehole with the valving sleeve in the first open port position;

moving the valving sleeve of the diverter device downward from the first open port position to a first closed port position;

moving the valving sleeve of the diverter device downward from the first closed port position to a second open port position; and

moving the valving sleeve of the diverter device downward from the second open port position to a second closed port position.

29. The method of claim **28**, wherein the step of moving the valving sleeve downward further comprises the steps of:

dropping a first ball into the yieldable ball seat, said first ball sealing with the yieldable ball seat;

increasing drilling fluid pressure to a first predetermined level above the first ball to move the camming sleeve from its first axial position to its second axial position and to move the valving sleeve from the first open port position to the first closed port position; and

increasing drilling fluid pressure to a second predetermined level above the first ball to expand the yieldable ball seat to allow the first ball to pass through the yieldable ball seat.

30. The method of claim **29**, further comprising the steps of:

dropping a second ball into the yieldable ball seat, said second ball sealing with the yieldable ball seat;

increasing drilling fluid pressure to a first predetermined level above the second ball to move the camming sleeve from its first axial position to its second axial position and to move the valving sleeve from the first closed port position to the second open port position; and

increasing drilling fluid pressure to a second predetermined level above the second ball to expand the yieldable ball seat to allow the second ball to pass through the yieldable ball seat.

31. The method of claim **30**, further comprising the steps of:

dropping a third ball into the yieldable ball seat, said ball sealing with the yieldable ball seat;

increasing drilling fluid pressure to a first predetermined level above the third ball to move the camming sleeve from its first axial position to its second axial position and to move the valving sleeve from the second open port position to the second closed port position; and

increasing drilling fluid pressure to a second predetermined level above the third ball to expand the yieldable ball seat to allow the third ball to pass through the yieldable ball seat.

32. The method of claim **30**, wherein the step of moving the valving sleeve downward comprises the steps of:

dropping a third ball into the yieldable ball seat, said third ball sealing with the yieldable ball seat;

increasing drilling fluid pressure to a first predetermined level above the third ball to move the camming sleeve from its first axial position to its second axial position and to detach the piston from the lower end of the inner sleeve of the volume compensation device and force the piston axially upward to provide volume for the sleeve of the diverter device to move downward from the second open port position to the second closed port position; and

further increasing drilling fluid pressure to a second predetermined level above the third ball to expand the yieldable ball seat to allow the third ball to pass through the yieldable ball seat.

33. The method of claim **28**, wherein the step of moving the valving sleeve downward comprises the steps of:

dropping a first ball into the yieldable ball seat, said first ball sealing with the yieldable ball seat;

increasing drilling fluid pressure to a first predetermined level above the first ball to move the camming sleeve from its first axial position to its second axial position and to detach the piston from the lower end of the inner sleeve of the volume compensation device and force the piston axially upward to provide volume for the sleeve of the diverter device to move downward from the first open port position to the first closed port position; and

further increasing drilling fluid pressure to a second predetermined level above the first ball to expand the yieldable ball seat to allow the first ball to pass through the yieldable ball seat.

34. The method of claim **28** wherein the step of lowering the tubular member into the borehole with sleeve in the open port position and the step of moving the diverter device to the second open port position each comprises the step of:

providing a flow path for drilling fluid to flow upward into the tubular member, through the volume compensation device and the diverter device, and outward into an annulus between the drill pipe and the borehole via the set of flow holes.

35. The method of claim **28** wherein the step of moving the surge pressure reduction device to the first closed port position and the step of moving the diverter device to the second closed port position each comprises the step of:

providing a flow path for drilling fluid to flow downward through the drill pipe, through the diverter device and the volume compensation device, and outward into the borehole via the tubular member.

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